

RUNNING HEAD: Word Learning in Mathematics

Word Learning in Sixth-Grade Mathematics Classes

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Abstract

The purpose of this study was to investigate aspects of word learning in mathematics classrooms where teachers relied to varying degrees on math textbooks for the substance and method of instruction. The purpose was to extend to our understanding of word learning in natural classroom environments with a focus on words that are not explicitly taught. Two sixth-grade mathematics classes studying the same unit (statistics) in the same book were given standardized and experimental interview to assess their word knowledge and their word learning during the unit. The classes did not differ in performance on pretest standardized tests of inferential word learning or on prior knowledge of topical words. After the unit, significant improvement in understanding of topical words was found for one of the classes. For both classes, inferential word-learning abilities and prior word knowledge contributed to performance on the posttest interview, but reading class assignment and accuracy of reading the topical words did not account for word learning during the unit. Observational data showed that the teachers used different instructional activities and differed in the amount of class time devoted to the unit. Both factors may have affected students' learning of topical words. The results suggest that heavy reliance on the textbook for math lessons might not provide sufficient support for students to deepen their understanding of basic terms needed to learn mathematics.

Word Learning in Sixth-Grade Mathematics Courses

Studies of incidental word learning have shown that students learn words from reading (Swanson & de Gloper, 1999). Both the characteristics of the text and of the readers affect the extent of word learning from reading (Jenkins, Stein & Wysocki, 1984; Nagy, Herman & Anderson, 1985). In math classes, where textbooks are often the primary reading material and the primary source of lessons and homework assignments, a major concern is the extent to which textbooks foster students' understanding of topical terms and the knowledge about topics conveyed by those terms. Recently, publishers of mathematics textbooks have tried to help students learn specialized vocabulary words in each unit. Key terms are highlighted, examples are given, and activities that might help students link new words to more familiar concepts and experiences are suggested. How helpful these changes are is unknown. A second issue concerns the teachers' use of the textbook as a tool for learning. In content-area courses, such as math, the textbook often provides the structure for the content (e.g., lessons and practice exercises). The teacher's instructional practices affect the extent to which students have opportunities apart from the lessons provided in the textbook to learn topical vocabulary. Teachers' use of the textbook and selection of learning activities might interact with students' inferential word-learning abilities in ways that either foster or impede both learning of words and, more broadly, acquisition of ideas and knowledge in content-area courses (Blank, 2001). At this time, very little is known about students' word learning in naturalistic classroom contexts, when that word learning is not primarily attributable to explicit vocabulary instruction.

What is the Process of Word Learning?

Incidental word learning is a process of inferring the meaning of a word from its use in a particular context. The inference about the word's meaning might be an initial sense of the probable meaning of a completely unfamiliar word, or it might be a new meaning or use of a familiar word. Very few words have fixed meanings; aspects of word

meaning are likely to change depending on the context in which a word is used (Anderson, DATE). Acquiring depth of knowledge about words requires that the student have sufficient flexibility to infer meanings of words from encounters in familiar discourse contexts. Word learning is associated with sustained talk and repeated encounters with given words. Further, the student is most likely to learn new words if there is a reason to do so--essentially, a reason to seek to make others' talk meaningful. These conditions provide a supportive structure or "cognitive context" for word learning to take place (Nelson, 1996). Social factors affect both the process of acquiring word meanings and the meanings so acquired (Domzalski & Gavelek, 1999). Word learning that takes place in school, whether through discussion in the classroom or reading textbooks, provides a basis for acquiring knowledge about topics in different domains, and for this reason is related to their achievement in academic courses (Carlisle, Fleming, & Gudbrandsen, 2000; Nelson, 1996).

In both textbook chapters in mathematics and in the teacher's treatment of the topic, certain words may need to be explicitly presented to the students, as they are inextricably tied to learning ideas and information in the unit. "New" words tend to be the content as well as the vehicle for conveying ideas and information (e.g., words like mean and median in a middle-school unit on statistics). Teachers generally define or explain such words to students, and textbooks highlight them and present definitions in the text or in a glossary. Other words are not specific to the content of the unit but nonetheless may serve as a foundation for learning the specialized words—for example, the words, average and estimate, in the same unit. Teachers may not think to explain such words to the students; rather, they simply use them as the basis for explaining the more specialized terms. Having some understanding of such words may be a crucial determinant of students' learning of the "content" words and the ideas and information in the unit of study. However, students may not be familiar with the particular meaning (reference) that is needed to understand and use that word in the context of math lessons. For

example, middle-school students are likely to have encountered words like average in other school contexts and possibly outside of as well (e.g., baseball average). Those who have a conceptual basis for understanding such words might extend an understanding of such words to include meanings specific to the math unit; others might lack the inferential processes to make such connections on their own.

What Factors Affect Word Learning?

Differences in opportunities to learn words may stem from the nature and amount of talk in the home and school settings, as well as the verbal and cognitive abilities of the learners. The consequence of these differences is a wide range in the size of school-age children's vocabularies. For example, Nagy and Herman (1987) estimated the vocabulary size for third graders to fall in a range of 4,000 to 24,000 words, with the median value of 10,000 words. Combined home and school factors appear to account for some the difference in vocabulary; for example, Graves, Brunetti, and Slater (1982) found that middle-class first graders read and understood 50% more words than their peers from low-SES schools.

Differences in the inferential processes that are the basis for incidental word learning also contribute to variability in the depth and breadth of word knowledge among students who are exposed to the same opportunities to learn words in school. The results of studies of word learning from controlled contexts (reading or watching a videotape) indicate that verbal ability, background knowledge, and reading ability affect the extent and depth with which meanings of words are inferred from context (e.g., Oetting, Rice, & Swank, 1995). Investigating a different aspect of inferential word learning, Nagy and Scott (1990) found that students differ in the extent to which they have word "schemas"--that is, understanding of not specific words but also about words in general, such as the probable part of speech or the meanings of component morphemes.

An individual's verbal and cognitive capabilities shape the development of their word learning from early childhood and consequently affect the depth and breadth of

word knowledge over time. Thus, vocabulary size is a good predictor of a student's incidental word learning potential. Shefelbine (1990) found that students with higher levels of general vocabulary learned more about words from reading a passage than the students with lower levels of vocabulary. Similarly, McKeown (1985) found that "low" vocabulary children had difficulty developing an understanding of semantic relations from exposures to words in different contexts. As a result, acquiring word meanings from context was limited, relative to that of "high" vocabulary students. It is not surprising, then, that children with language-learning disabilities learn fewer words through casual exposure in language contexts (Oetting, et al., 1995).

In mathematics, as in other domains, words assume meanings particular to the knowledge structures and concepts of that domain. Graves (1984) pointed out that words are labels that represent concepts. A student could know the label without having a solid conceptual foundation for this knowledge; alternatively, he or she could have a conceptual representation without the verbal label. There are indications from reading research that students are more likely to learn unfamiliar words for which they have an available concept than words for which they have no available concept (see Shefelbine, 1990).

A related factor is background knowledge. Domain knowledge provides a network of semantic and conceptual links that facilitate new learning (Nelson, 1986). Stanovich and Cunningham (1993) have suggested that domain knowledge, in addition to cognitive and linguistic abilities, influences learning of words and concepts in specific content areas. Students may have relevant knowledge acquired from previous experiences with the topic or domain—or related knowledge acquired through other experiences or courses in school. Carlisle, Fleming, and Gudbrandsen (2000) found evidence of gradual increases in depth of words used to talk about the topic in science units. Students' learning of words in a science unit showed that increases in word knowledge and conceptual knowledge were interactive, not causally unidirectional. A student who started

a unit with little or no knowledge of words was likely to make some gains but probably not to appreciate the full intent of the word as it was used in the science unit. For example, before a unit on separation of substances, one eighth grader associated the word distillation with a kind of water her mother used in her iron, but she could not explain what the word meant or why her mother was using distilled water. Through the science experiments and discussion, she acquired procedural knowledge about how distillation was carried out in the science class, but her conceptual grasp was still limited.

Together, inferential word-learning abilities and prior knowledge of topical vocabulary may affect a student's ability to learn in that content area. Students may have a concept associated with the meaning of a word in a familiar context, such as their home lives, but this may not transfer readily to the meaning(s) intended in a given academic domain. For example, using an interview based on picture prompts, West and Pines (1985) found that students' understanding of words related to physics principles were very different from those the teacher intended. Other researchers (e.g., Lewis & Linn, 1994) have found that students may not readily relinquish initial concepts. They may tolerate and parrot back information the teacher conveys in the unit of study but fall back on earlier alternative understandings sometime over time. We might expect that conceptual foundation of word knowledge is better than having a verbal label that is only that—an associative label with no conceptual understanding. However, we cannot infer that commonly used words have a meaning that is readily transferred to or applied to content-area learning.

Word Learning in the Context of Classroom Activities

As noted earlier, students have been found to make significant gains in learning words from texts. However, skilled readers acquire more word knowledge than less skilled readers (Jenkins, Stein & Wysocki, 1984 ; Nagy et al, 1985; Swanborn & de Glopper, 1999). Lack of experiences with written texts that contain unfamiliar words and relatively weak decoding skills might affect students' processing of texts for meaning,

including reducing the incentive to analyze the meanings of unfamiliar words. In reading, the context for learning includes no verbal or social interaction, and presumably such interactions would aid students in the process of inferring meanings of unfamiliar words. In contrast, learning in classrooms is typically both verbal and interactive. Students have the opportunity to construct meanings from the interplay of events, experiences, and verbal references.

When teachers use textbooks to dictate the content of a unit, the decisions they make regarding instructional activities, the length of the unit, and so on are likely to affect students' learning. Through discussion and activities that link words to content-related meanings, teachers help students develop an understanding of the words that are needed to communicate concepts and information (Lemke, 1990). In science, studies have shown that students tend to commence a unit of study with primitive understanding of relevant concepts or with misconceptions, often referred to as alternative conceptions (Lewis & Linn, 1994). Students' understanding of topical terms may reflect commonplace uses of words without the semantic and conceptual underpinnings that allow them to understand the teachers' use of the words (Meyerson, Ford, Jones, & Ward, 1991; West & Pines, 1985). Students' movement toward the appropriate meanings and concepts may be dependent on active processing or engagement. Teachers' common use of tri-part questioning (i.e., initiation, response evaluation) may stimulate students' awareness of their own knowledge, but other activities may be more powerful in prompting students to adapt or reconstruct their preliminary notions. These might include student-generated questions, "true" discussion, group work and lab work (Lemke, 1990). Lewis and Linn (1994) suggested that discussion of students' background knowledge and key concepts provides a foundation for learning words in the scientific sense and facilitates conceptual change.

Similar views have been expressed concerning learning of mathematics (O'Connor, 1998). With the current emphasis on mathematical reasoning and problem

solving in the standards of the National Council of Teachers of Mathematics, teachers and researchers have been concerned with aspects of classroom communication that support students' learning. Of importance is the development of "habits of mind" that underlie scientific and mathematical problem solving (O'Connor, 1998, p.22).

Communication between students and the teachers, as well as among students, holds the promise of fostering the development of mathematical reasoning. In the process of learning to reason mathematically and to explain their reasoning, students would also be inferring the meanings of topical terms as they are used to explain central ideas, processes, and activities in the unit. The meanings of key terms are context-sensitive and are negotiated by participants working jointly to solve problems (Domzalski & Gavelek, 1999). Thus, in classrooms that rely heavily on textbooks for lessons, activities, and practice exercises, it is possible that students might not participate in discussions or engage in the type of reasoning that would foster their topical word learning.

Design of the Study

The study reported in this paper was designed to investigate factors that affected sixth graders' word learning over the course of a unit of study in math. It focused on two classrooms in which the teachers used the same textbook and taught the same unit but chose their own instructional methods and activities. At the teachers' recommendation, we followed a unit was based on Chapter 2 in the textbook, Glencoe Mathematics: Applications and Connections, Course 1 (1999) called Statistics. Previous work (Carlisle et al., 2000) had indicated that students vary in their understanding of topical words used to convey ideas and information. We selected words from the textbook chapter that were central to explanations and activities (e.g., average) but were not highlighted in the textbook for special attention (e.g., bar graph, mean, median). Students might be familiar with a word like average; our question was whether they would be able to demonstrate improved understanding of the meaning of such words as they were used in the chapter by the end of the unit. It was our expectation that student's inferential word-learning

abilities and prior knowledge of such basic topical words would support their learning of the meanings and uses of the words in the context of the mathematical unit. However, we also were interested to see whether the teacher's instructional activities appeared to mediate the students' word learning.

The research questions were as follows: (a) Are there differences in topical word learning over the course of a unit of study for students in the two math classes, when initial levels of word knowledge are controlled? (b) Do inferential word-learning capabilities and reading proficiency contribute to growth in students' topical word knowledge, when differences in pre-test topical word knowledge are taken into account? (c) Do the activity structures used in the two math classes differ? And (d) does class membership affect word learning in math, when differences in inferential word-learning capabilities and initial word knowledge are controlled?

Method

Subjects

Subjects were sixth-grade students in two mathematics classes in a public middle school in a mid-size midwestern city. In this school system, 45% of the students were Black, 44% White, 8% Hispanic, 3% Asian or Pacific Islander, and 0.1% American Indian or Alaskan native. Thirty-five percent of the students in the school came from low-income households. Of the 17 students in Teacher A's math class, 12 participated in the study (7 boys and 5 girls). Of these, 5 attended a special reading class for students scoring below the 3rd stanine on the standardized reading test used by the district. Of the 19 students in Teacher B's math class, 18 participated in the study (6 boys and 12 girls). Five students attended the special reading class. The mean age of the students in each of the classes was 11.7.

The students were given two subtests of the Test of Word Knowledge (TWK) (Wiig & Secord, 1991) to assess their inferential word-learning capabilities: Definitions and Multiple Contexts. Table 1 shows the students' scaled scores on these measures by

class; the two classes did not differ on the mean scaled scores on these subtests; for Definitions, $t(??) = 1.74$, $p = .09$; for Multiple Contexts, $t(27) = .81$, $p = .42$. For both classes, performance was somewhat below average on the TWK subtests.[check]

Table 1 about here

The Teachers and Their Unit Plans

Teacher A has been teaching for 25 years. She started her career as an English teacher, but had been teaching mathematics for 14 years. We followed her first period class, which she told us had a number of students with behavior problems. The class period quite consistently had three parts: going over homework, introducing the new lesson, and working on problems that involved the new lesson (often the beginning of the homework assignment). Teacher A relied heavily on the textbook for instruction and homework assignments.

Teacher B has been teaching for 12 years, including 5 years of mathematics. We followed her third-period class for the unit on statistics. Like Teacher A, Teacher B broke the class period into three activities. She too used the textbook as the source of information for the unit, but she used a greater variety of instructional activities. On one day, for example, she divided the class into small groups to solve problems. On several occasions, she had individual students write the solution to a homework problem on a transparency and then show the solution to the class for discussion.

Teacher A's unit on statistics ran for a total of fifteen class periods, whereas Teacher B's unit covered a total of twenty-four class periods.

Materials

Standardized Tests: As noted above, the students were given two subtests of the Test of Word Knowledge (Wiig & Second, 1991): Definitions and Multiple Contexts. On the Definitions subtest, students are asked to explain the meanings of words (e.g., mansion); this task taps students' knowledge of key semantic and conceptual characteristics of words (e.g., "What is a mansion?"). On the Multiple Contexts subtest,

students were asked to give two meanings (or uses) of a each word; for example, for glasses, a student might say, "You drink out of glasses, and glasses are something you wear to make your eyesight better." The task taps depth and flexibility of word knowledge.

Experimental Measures. An experimental pre- and post-testing interview was designed to measure the students' growth of topical word knowledge over time. The words used for this measure came from a pool of words drawn from the textbook chapter on statistics. From this list, we selected words that were not key content words in the chapter but were likely to be familiar to sixth graders (e.g., prediction). This was because we were interested in the students' ability to infer meanings from textual encounters with the words, as opposed to their learning of words that the text and teacher were likely to explain explicitly for the students. We also asked the students to read a list of topical words taken from the chapter; this measure was administered during the post-testing

(a) Interview: This measure was designed as a measure of students' knowledge of words related to statistics and graphing; the items were such that understanding could be demonstrated by explanation or, in some cases, by a pointing response. There were two forms of the measure--one used for the pretest and one for the posttest. They were identical except for the content of the line and bar graphs. For example, the pretest bar graph (shown in the Appendix) showed the pets belonging to students in two classes, whereas the posttest bar graph showed the cities visited by students in two classes. The student was asked questions about the two graphs (a line graph and a bar graph) that required identifying, defining, and apply knowledge of topical words. The questions used for the bar graph and scoring criteria for those questions are shown in the Appendix. One other feature of the posttest was follow-up probes requesting definition of the meanings of five words (e.g., axis, scale, interval, range, and average). In each case the probe was administered at the end of the interview item that focused on that particular term.

(b) Reading Word List: The students were asked to read a list of 22 topical words. The purpose was to determine whether differences in word reading accuracy affected learning from the textbook over time.

Procedures

Test administration. The two standardized TWK subtests and the pre-test Interview were administered individually several days before the start of the unit. Time of administration was about 20 minutes. At the time of post-testing (approximately 3 weeks after the completion of the unit), students were given the post-test Interview and the Reading Word List individually.

Classroom observations. The researcher and trained research assistants observed 13 out of 15 of Teacher A's mathematics classes and 23 out of 24 of Teacher B's classes in the unit. We used a measure of interval recording for classroom observations. A Palm Pilot was used to record aspects of classroom activity every 5 minutes. Detailed field notes were taken as well. Aspects of classroom activities that are typical for mathematics lessons were selected for data recording; we also used Lemke's analysis of activity structures in science classes, as many are common to content-area classes. The categories of academic interest were (a) going over homework, (b) external text dialogue (i.e., talking about the text), (c) teacher exposition/triadic dialogue (i.e., explanation and discussion), and (d) small group work. More than one type of activity could be marked during a given five-minute interval. For example, if a teacher finished going over homework and moved on to explain a new concept (teacher exposition), both activities would be noted as occurring in that five-minute slot.

Scoring procedures. Responses from the Interview tests were scored independently by two researchers. For the Interview tests, criteria for an accurate response (or components thereof) were established a priori; these provided guidelines for scoring. (Criteria for the bar graph are given in the Appendix) The student's score was the total of the correct responses or components of responses. For example, to answer the

question, "What is an axis on a graph?" the student might point to the bottom line on the graph and in doing so received one point. If the student was also able to say what an axis is, he or she received another point. The correlation of scores assigned by the two raters for the Math Interview test was .96 for the pre-test and .95 for the post-test. The Reading Word List score was the total number of words read correctly.

Results

Improvement of the Two Classes

The first question was whether the students in the two math classes demonstrated improved knowledge of topical words three weeks after the end of the unit on statistics. Table 2 shows the performance of the two classes on the pre-test and post-test Interview. Analysis of variance was carried out with one between-subjects factor (class A and B) and one within-subjects factor (time of administration). The results showed that the effect for class was not significant, $F(1, 28) = .98, p = .33$; however, there was a significant effect for time, $F(1, 28) = 34.83, p < .001$, and a significant interaction, $F(1, 28) = 8.64, p < .001$. Post hoc analyses (Tukey's HSD for unequal groups) indicated that the two classes did not differ on the pre-test Interview, but differed significantly on the post-test Interview ($p < .05$). The effect size was carried for each class (difference between the post-test and pre-test mean divided by the pooled standard deviation). The result showed a moderate effect size of .461 for Teacher A and a large effect size of 1.32 for Teacher B.

Table 2 about here

On the post-test Interview, we compared the classes' performance on the follow-up probes used to determine whether students could give definitions for the target terms (e.g., axis) and found that they differed significantly. Students in the class that made significant growth during the unit (Teacher B's class) were also significantly better at defining the terms, $t(31) = 2.24, p < .05$.

The two classes did not differ on the Reading Word List measure. Teacher A's class read an average of 19 words correctly (1.4 SD), while Teacher B's class read an average of 19.8 words correctly (.53 SD).

Contribution of Inferential Word-Learning and Reading Skill

The second question was whether inferential word-learning abilities and reading achievement status influenced students' word learning during the unit. The two standardized subtests of word knowledge (the average of the scaled score on the Definitions and Multiple Contexts subtests) and reading group (a rank-order variable to designate those who received assistance in reading and those who did not) were significantly correlated with performance on pre-test and post- test Interview, as Table 3 shows. Reading group was also significantly related to performance on the TWK subtests: for Definitions, $r = .43$, $p < .05$, and for Multiple Contexts, $r = .46$, $p < .01$.

Table 3 about here

Hierarchical, forced-entry regression analyses were carried out to determine whether inferential word-learning abilities and reading group assignment accounted for significant variance on the post-test measures, when the effects of pretest performance on the measure was accounted for. The regression analysis was carried out by switching the order of entry of language scores and reading group, so that the relative strength of the contribution of each of these variables could be determined. Table 4 shows the results of these analyses.

Table 4 about here

For the Interview, the pretest, entered first, accounted for a significant 38% of the variance on the post-test. When the language scores were entered second, they accounted for an additional 29% of the variance. Entered third, reading group did not contribute significantly. When the order of entry was reversed, the results did not change. Entered second, Reading group was still not significant, but language scores (entered third) were

significant. All told, the variables together accounted for 69% of the variance on the post-test Interview, $F(4, 25) = 13.77, p < .001$.

Differences in Instructional Activities

The third question was whether the classes differed in instructional activities, when equated for total instructional time spent on the unit. We tabulated number of 5-minute intervals in which each type of instructional activities had been noted during our classroom observations. The totals were converted to represent percent of opportunity, since the units in the two classes differed in duration. These results are shown in Table 5. A Chi Square analysis indicated that the activities used in the two classes were significantly different, $\chi^2 = 12.47, p < .01$. Follow-up analyses showed that the sources of difference were External Text and Teacher Exposition and/or Triadic Dialogue.

We were also interested in whether differences in teachers' unit lessons (learning activities, ways of interacting with the textbook, etc.) influenced word learning, as assessed by the Interview. Hierarchical multiple regression analysis was carried out by entering class membership (a dichotomous variable) last, after the pre-test Interview score and language scores. Table 6 shows the results of this analysis. Entered second, inferential word-learning capabilities accounted for an additional 28.7% of the variance, and entered third, class membership accounted for an additional and significant 5% of the variance on the post-test Interview. Together the variables accounted for 72% of the variance, $F(4, 25), p < .05$. Thus, differences in class membership contributed to differences in word learning in this particular unit.

Discussion

This study was designed to investigate the nature of word learning in math classes, with a interest in how students' word-learning abilities (inferential skills and prior knowledge of topical terms) and teachers' methods of using the math textbooks affected learning of topical words, but not those that were especially singled out as the content of the unit on statistics. We were interested in the extent to which students' inferential word-

learning ability and reading ability would contribute to improvement in their topical word knowledge during a unit in mathematics. We were also interested in the extent to which the teachers relied on the textbook to teach new information and terms and as the basis for class activities. Because foundation words, like average and vertical, are crucial for learning ideas and information in content-area units, we hoped to gain insights into the circumstances that foster effective use of math textbooks for sixth graders. We know, of course, that research in classrooms can be complicated by factors other than those selected for study; as a result, this study must be regarded as an exploratory effort to study word learning in content-area classes.

Learning Topical Words

Our focus was on students' learning of what we think of as foundation words—that is, words that teachers and students are likely to use to discuss ideas and information in a particular unit of study. These aren't words for which the teachers and textbooks are likely to provide explanations, but rather those words that teachers assume their students know and that are central to explaining ideas and information in the unit. We compared growth of knowledge of such words for students in two sixth-grade math classes. Comparison of performance on the pre- and post-test Interview showed modest and insignificant growth for one class (effect size of .461) but significant growth for the other class (effect size of 1.32).

Did students' characteristics and teacher's instructional methods influence these outcomes? Two factors may have worked together to bring about the relatively small amount of progress the students made in their understanding of foundation words during the unit. First, some of the students in both classes had significantly low scores on the standardized subtests of the Test of Word Knowledge. Limitations in inferential word-learning abilities might well have affected their ability to pick up the meanings of foundation terms from the textbook or from their teacher's instructional discourse. Second, the structure of learning activities and the length of the units might not have

provided sufficient opportunities for students to integrate their prior knowledge of topical words with semantic and contextual features in the area of statistics. The first of these explanations may help us understand the generally low levels of word learning for students in both classes. The second explanation suggests one reason that only one of the two classes made significant progress.

The Interview required students to identify and/or explain parts of a graph or to interpret information on it (e.g., "What was the average number of dogs for first graders in Johnson's class?"). The better of the two classes earned 41% of the possible points on the post-test. The relatively low level of performance on this post-test indicates that, even after the students had worked with statistics for a number of weeks, many of them had difficulty demonstrating or explaining meanings of common topical words (e.g., range). On the other hand, given follow-up queries about the meaning of certain terms, the students in KR's class were more able to define the words three weeks after the unit was over than students in DL's class. Thus, modest though their progress was, some of them appeared to have gained a good conceptual grasp of key terms of the unit.

Post-hoc scrutiny of students' pretest performance on specific words showed that they had trouble understanding words like "range" and "average" when they were central to questions that they were to answer by referring to a line or a bar graph. For example, on the pre-test Interview, 77% of DL's students and 72% of KR's students could not identify the range of numbers for the scale of a bar graph; 77% of DL's students and 89% of KR's students could not tell us the average number of dogs owned by students in two first-grade classes (as shown on the bar graph in the Appendix). They also could not tell us how to calculate an average. Most said that average meant "the middle" but could not explain this response further. On both of these words, we saw lots of progress but still many students left without a clear understanding of the two terms. After the unit, on a very similar graph, 15% of Teacher A's students and 33% of Teacher B's students were unable to identify the range of numbers on a scale on the graph; 38% of Teacher A's

students and 67% of Teacher B's students could not read the graph and then calculate the average number of sixth-graders in two classes who visited Seattle. In short, words central to students' understanding of key concepts in the unit were not necessarily learned just because they were exposed to them through reading and discussion during the unit.

Making Sense of Word Learning in Context

The two mathematics classes were not different in inferential word learning ability (as measured by the Test of Word Knowledge subtests) or age. They were studying the same unit in the same book at the same time of year. How do we explain the differences in the progress in topical word knowledge demonstrated by the two classes? Two aspects of the two teacher's units may have had an impact on both of these results. One is the overall length of time devoted to the unit and the activity structures used by the teachers. Comparison of the major activities used by the teachers was carried out in a way that took into account overall differences in length of the unit. That is, the different types of instructional activities were represented as percent of opportunity. This analysis showed significant differences in the proportion of class time devoted to different learning activities. The main differences were in the use of the textbook as the focus for lessons (more commonly used by Teacher A than Teacher B) and in the use of exposition and/or triadic dialogue with the students (more commonly used by Teacher B than Teacher A).

It is possible that reliance on the textbook to organize learning and class activities led to only partial understanding of certain terms and the methods used to make and interpret graphs. However, it is likely that the length of the units also affected learning. The brevity of DL's unit may have meant that students had insufficient time to integrate the separate lessons and activities and few opportunities to practice what they were learning, and these are two important characteristics of effective instruction in mathematics (Lemke, 1990; O'Connor, 1998; Rittenhouse, 1998). Analyses showed that class membership contributed to performance on the posttest Interview, once the effects

of prior knowledge and word-learning abilities were accounted for. The class variable would presumably reflect differences in the length of the unit and in the instructional activities used by the two teachers. It is also possible that this variable includes other differences between the two classes that we did not measure. Two such differences are the behavioral climate of the classroom and the discourse practices of the teachers and students. Although we are not able to explain why class membership made a significant difference on the Interview performance, the results raise the possibility that the nature of the learning environment might interact with the prior word knowledge and inferential word-learning ability of the students in influencing their word learning during units of study.

The Contribution of Semantic and Metalinguistic Development

The students' pre- and post-unit performance on the Interview indicated that prior knowledge of words contributed significantly to the post-test performance, as did students' inferential word-learning abilities. Furthermore, the fact that performance on the standardized word knowledge measures was significantly related to performance on the pre- and post-test Interview measures may indicate that inferential word-learning ability is tied to previous as well as present understandings of meanings and uses of words in a unit such as the one we followed.

In contrast, students' reading skills did not contribute significantly to post-test performance on the Interview, once pre-test word knowledge effects were controlled. While we found significant correlations between reading group and both the experimental and standardized language measures, in the regression analyses, prior knowledge of topical terms was more powerful in predicting performance on the post-test. It is important to point out that the variable used here was a group label, one that indicated the students who did or did not take a special reading course (those assigned this course had received scores on a standardized measure below the 3rd stanine). This is not a strong measure of reading ability. For this reason, we cannot conclude that differences in

reading ability were unrelated to growth of word knowledge during the unit. An additional bit of evidence that reading was not a critical factor was that most students in both classes read the topical words aloud with a high level of accuracy. We nonetheless feel that the impact of reading skill on word learning in mathematics should be studied further. We observed a number of students struggling to read math problems in their textbook, so that it seems possible that under different circumstances we might find a stronger relationship between reading ability and word learning, when textbooks are the source of information and practice problems.

Instructional Implications and Questions

Two aspects of instruction seem to stand out as important to consider, given the results of this study. The first involves the students' prior knowledge of topical words and inferential word-learning abilities. These exerted separate and significant influences on word learning in the statistics unit in these classes. It is educationally noteworthy that a number of students in the classes demonstrated below average inferential word-learning ability. To address both factors, teachers might need to select learning activities that have the potential of helping students learn foundation terms; they might choose activities that can convey basic concepts and use pre-reading activities to build background knowledge (references).

While some of the sixth graders in the two math classes told us they were familiar with words like average and range, even after the unit on statistics was over, they often could not explain the meanings of the words clearly and or demonstrate knowledge of the meanings of the words by referring to parts of the graphs or information shown on the graph. One wonders if such students would have made greater progress had efforts been made to help them bridge their initial understanding of topical terms with the concepts and meanings that are important for learning in the unit of study (Lewis & Linn, 1994).

A second finding that has instructional implications has to do with the choice of activities. We cannot conclude that the results show the important role of discussion in

word learning, but we have at least enough evidence to suggest that this possibility should be pursued further. Such a suggestion is supported by research in other content areas, including science and literature (Lemke, 1990; other refs). Some types of instructional activities appear to be more likely than others to provide conditions in which students acquire understanding of topical words that are needed for understanding and learning ideas and information. Engaging students in thinking and talking about their mathematical thinking may foster a better understanding of topical words and concepts central to the unit. In the present study, Teacher B's class had many more opportunities than Teacher A's class to listen to her explanations of ideas and procedures and to discuss them with her. Such discussions may help students focus on key issues and ideas in ways that the textbook does not, even when the teacher spends considerable amounts of time going over the lessons in the textbooks.

Classroom discourse may play a particularly important role in students' word learning in content-area courses. In mathematics, the nature of communication among students and the teacher is generally believed to affect learning goals and outcomes (Cobb, Wood & Yackel, 1993; O'Connor, 1998; Rittenhouse, 1998). Further, processes of acquiring word knowledge are a natural part of learning from classroom discourse. Words are both the content and the means of learning. As Domzalski and Gavelek (1999) have argued, the meanings of words are negotiated through social-verbal interaction, and they are a natural result of the reiterative inferential processes that map the intended meaning of the speaker and the expectation of the listener. Particularly in the case of words that are not explicitly defined or explained by the teacher, students' and teachers' discussion provides a means for developing mutual understandings of the words used to talk about ideas in a given domain or unit of study. Because of the critical role of word learning in content-areas, future studies need to be designed to help us understand aspects of classroom instruction such as discussion that are most likely to facilitate word learning.

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Table 1

Mean Performance of Two Mathematics Classes on Test of Word Knowledge,
Definitions and Multiple Contexts subtests

Class	Definitions	Multiple Contexts
Teacher A	8.58 (1.50)	8.92 (2.97)
Teacher B	9.76 (1.99)	9.70 (2.97)

Note. Standard deviations are given in parentheses.

Table 2

Pre- and Post-Test Performance on the Mathematics Interview, Expressed as Percent of Possible Points

Class	Pre-test	Post-test
Teacher A	27.54 (9.43)	32.41 (11.62)
Teacher B	26.63 (10.21)	40.52 (12.23)

Note. Standard deviations are given in parentheses.

Table 3

Correlations of TWK Subtests (Definitions, Multiple Contexts) and Reading Group with Performance on the Pre-test and Post-test Interview

	Pre-test	Post-test
Definitions	.56***	.73***
Mult Contexts	.62***	.78***
Rdg group	.49**	.51**

* $p < .05$, ** $p < .01$, *** $p < .001$

Table 4

Contribution of Inferential Word-Learning Abilities and Reading Group to Performance on the Post-Test Interview, Controlled for Effects of Pre-Test Performance

Step/Variable	Mult R Sq	R Sq Change	F to enter	p-level
<u>INTERVIEW</u>				
1 Pretest	.38	--	17.50	.000
2 TWK	.67	.29	23.52	.000
3 Reading Gr	.69	.02	1.33	.259
2 Reading Gr	.44	.06	2.86	.102
3 TWK	.69	.24	20.35	.000

Note. TWK = Test of Word Knowledge subtests; Gr = group.

Table 5

Frequency of Activities in Two Mathematics Classes, Expressed as Percent of Five-Minute Intervals

Class	Going over Homework	External Text	Group Work	Teacher Exposition and/or Triadic Dialogue
Teacher A	38	45	0	22
Teacher B	40	23	4	31

Table 6

Contribution of TWK and Class Membership to Post-test Interview Performance,
Controlled for Pre-Test Performance

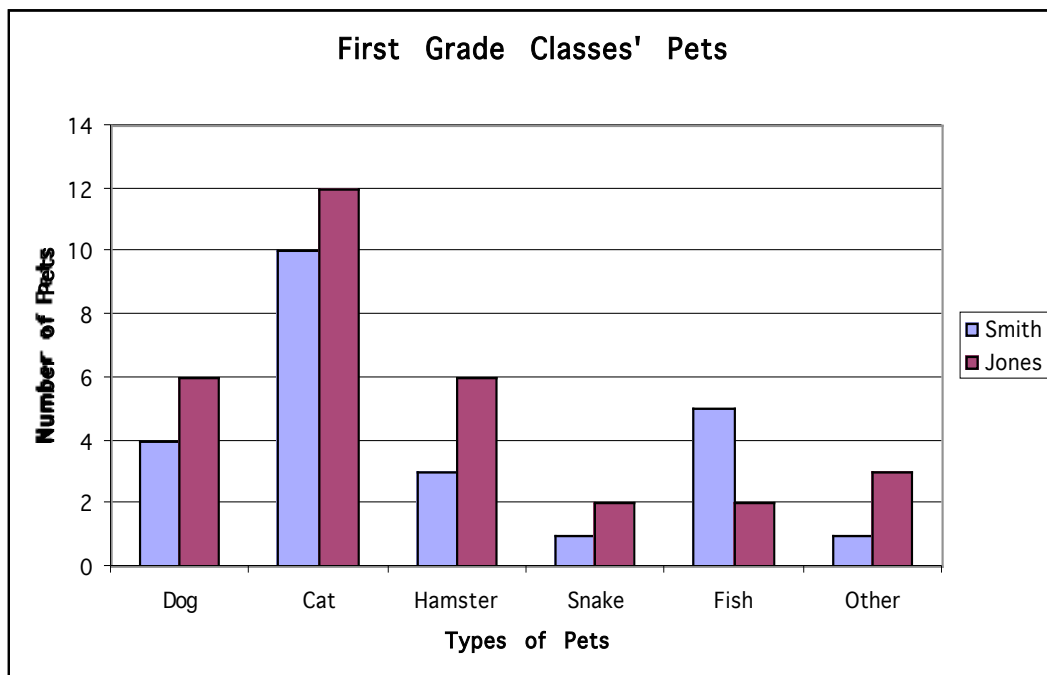
Step/variable	Mult R Sq	R Sq Change	F value	p level
Pre-test Int	.38	---	17.50	.000
TWK	.67	.29	23.52	.000
Class	.71	.04	3.97	.050

Note. TWK = Test of Word Knowledge subtests

Appendix

Words on Reading Word List Test

vertical	analyze	avrage
tally	axis	coordinate
survey	estimate	frequency
summarize	graph	intersection
segment	pattern	percent
scale	prediction	range

Pre-Test Interview: Bar Graph

Pre-Test Interview Questions and Scoring Criteria: Bar Graph

1. (a) Tell me what you learn from this graph. (b) Tell me about the parts of the graph.

Explains purpose of graph

_____ read title

_____ explains purpose in own words

Identifies parts of the graph accurately

_____ explains vertical scale {"how many . . ."}]

_____ identifies code for classes

_____ interprets code for classes

_____ tells about horizontal axis

_____ make correct interpretation about results

2. What is the average number of dogs in the two first grade classes? [Probe: How did you decide on your answer?]

_____ correctly gives the average

_____ correctly explains process for getting an average

3. Are the bars on the graph vertical or horizontal?

_____ selects vertical

4. If you added another first-grade class to this chart, what kind of pet would you predict would be the most popular?

_____ correct prediction is cat

5. Estimate the total number of pets in the two classes.

_____ gives a figure between 45 and 70 (DOES NOT add all the numbers)

6. How do you do a survey to make a graph like this?

Describes collection of information and analysis of information

_____ mentions asking people to tell about XXX

_____ mentions writing down what they say

_____ mentions tallying responses

_____ mentions making a frequency table

Tells about process of making graph itself

_____ using color coding to represent groups

_____ deciding on intervals to use

_____ making height of bars to make #s on frequency table

_____ putting labels on graph

_____ putting title on graph

Note: Targeted topical words are underlined.